Holistic investment decisions based on life cycle models

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Abstract
In today's society characterized by digitalization and global markets, of course companies cannot solely base their decisions upon ecological criteria. Still, it is common sense that ignoring environmental aspects is not an option for a company that wants to be continuously successful. However, when it comes to strategic investments often the traditional concept of decision making is applied which focuses on investment and return of investment periods mainly. By implementing Life Cycle Thinking (LCT) with Life Cycle Models a whole new range of economic aspects becomes visible that might lead to overall more efficient investment decisions at lower cost over the entire life cycle. As a by-product, often economic efficiency comes along with environmental benefits as well.

For sustainable investment decisions it is crucial to execute a life cycle based comparison of available technologies or offered systems. This analysis has to be based on the technological characteristics of the systems meaning that a quantitative input-output analysis has to be done. Spreadsheet based Life Cycle Models, developed by LCS Life Cycle Simulation GmbH, can help to structure and document the analysis and support a transparent comparison of technological key parameters. Derived from that a thorough cost analysis can be done. Cost contributors can be identified along the life cycle of capital goods. A holistic technology benchmark reveals economic strengths, weaknesses and potentials. Once a Life Cycle Model is built-up it can be calibrated with actual cost data to run sensitivity and scenario analysis for ongoing monitoring and continuous improvement.

The successful application of spreadsheet based Life Cycle models for investment decisions will demonstrate the business case.

Introduction – Sustainability
Our world is characterized by many dynamic processes like consumption of resources or growth of population. If these processes follow a behavioural pattern as shown in Figure 1, it is most likely that they are not sustainable. Unsustainable developments have at a certain point an excessive increase of a single resource like crude oil or natural gas, a short maximum followed by a strong decrease. At the moment, for example the world's fossil fuel consumption has this trend of an excessive increase. And the big unknown is: What happens with our world (society, economy and ecology) at the period of strong decrease if we still continue our businesses unchanged?

We are able to create a sustainable future with this knowledge and our technical skills and expertise. In particular we have to manage:

- The increase of dynamic in all kind of processes and additionally the increase of complexity (together called "dynaxcity"). Implementation for investment decisions: up-to-date and specific data is crucial.
- The overall view ("bird's eye view") versus the view into details of products and technologies with regard to their impacts. Implementation for investment decisions: Details mean for example technical characteristics like energy consumption of an important process step. The overall view is the life cycle of a product, i.e. which has the most impact: production or use or recycling or end-of-life.

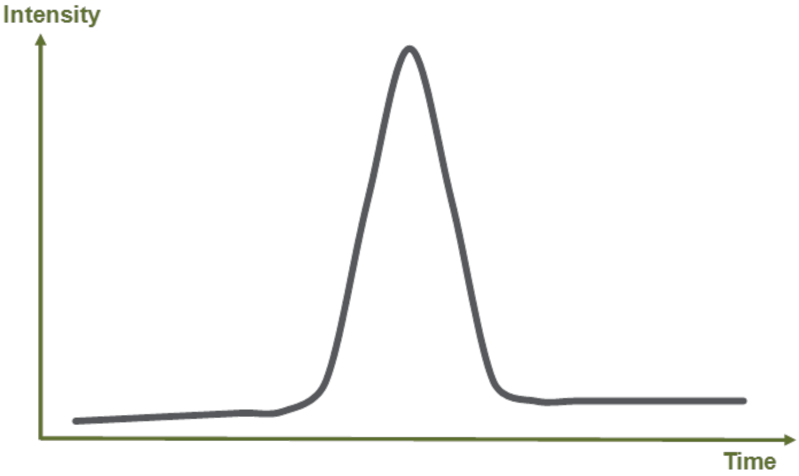

Figure 1. Characteristic development of unsustainable processes.

- The interaction between economic sphere (including technology), ecosphere and society, i.e. the so-called pillars of sustainability. Implementation for investment decisions: interaction implies the interlinkage of a new product, i.e. technical value (example: full electric vehicle), economic value (higher investment, lower operating costs), environmental value (zero emissions in cities) and social value (jobs in a new economy).
- The permanently changing boundary conditions in our world (politics and evolution). Implementation for investment decisions: evolution stands for the development of technologies, e.g. drive concepts of vehicles: battery or fuel cells or hydrogen. Changes in politics can be new trade agreements which influence entries to new markets.

Therefore, we have to advance our tools to describe these challenges. The tools must create transparency to identify the key drivers for a holistic optimization. Then options for a rearrangement should be prepared. Finally, a holistic evaluation should ensure the implementation of the most sustainable solution.

Figure 2 illustrates the methodical and technical approach of the company LCS Life Cycle Simulation GmbH to manage this important knowledge by:

- Building-up of specific customized life cycle models for products and technologies (important boundary conditions are: production site (i.e. energy and material supply, initial situation of all costs), used technology (i.e. old, state-of-the art, innovations possible ?) and working time model (i.e. 1 or 2 or 3 shifts).
- Applying a holistic evaluation:
  - economy: analysis of costs per unit (static cost calculation) or net present value (dynamic cost calculation), identification of cost drivers and limits of profitability,
  - ecology: analysis of environmental impacts like resource depletion, generated emissions (e.g. carbon footprint, water footprint, etc.),
  - technology: identification of yields in processes (e.g. coat on a product and respective overspray) and limits of technologies (e.g. current discussion about diesel engines which need an additional chemical to fulfil emissions threshold values),
  - societal boundary conditions: e.g. conservation of qualified employment.

Summing up, knowledge management is the approach to create life cycle models with all-round information to do a multidimensional evaluation, i.e. technology, economy, ecology.

Holistic investment decisions

The methodology – life cycle simulation models – combines holistic and sustainable thinking with transparent spreadsheet-based simulation tools and internationally accepted standards. Using the capabilities of sensitivity analysis[1] and scenario analysis[2] the models are fast and flexible tools for management and improvement decisions. They can be used for any kind of system and is not restricted to a specific industry sector.

Life cycle simulation models can be applied to evaluate products, processes or even entire production sites. An even more strategic application is to support sustainable investment decisions when it comes to acquire new production lines or other capital goods.

The procedure of decision making for long-term investments is of essential importance (Figure 3). Appropriate technological and economical evaluation of different offers in the early phase of the decision making process is essential in order to reduce the overall cost of the investment in later phases of the life cycle (reducing so called hidden cost). Aware of this fact, the classical procedure has to be complemented by two additional steps, i.e.:

1. Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system can be apportioned to different sources of uncertainty in its inputs [1].

2. Scenario analysis is a process of analyzing possible future events by considering alternative possible outcomes. It is designed to allow improved decision-making by allowing consideration of outcomes and their implications [2].

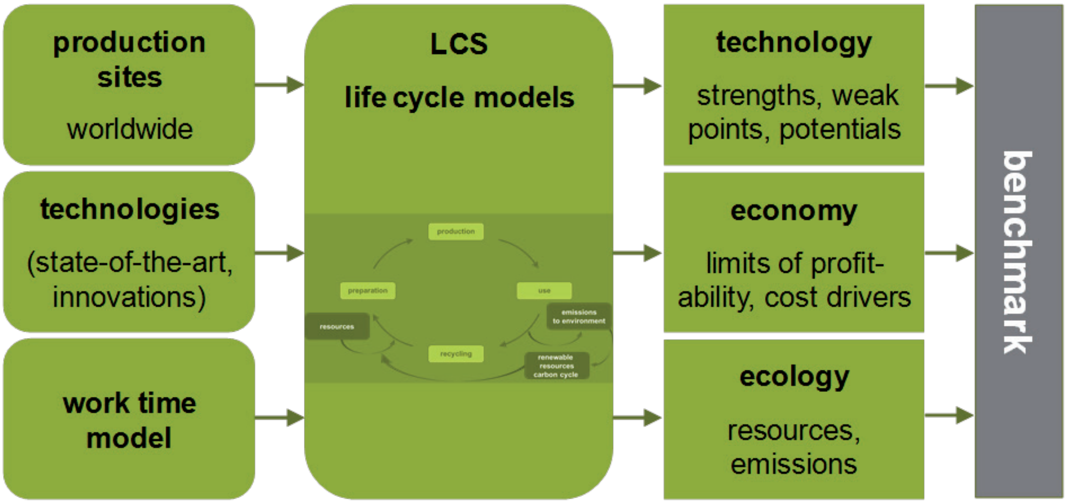

Figure 2. Knowledge management – part of LCS services.

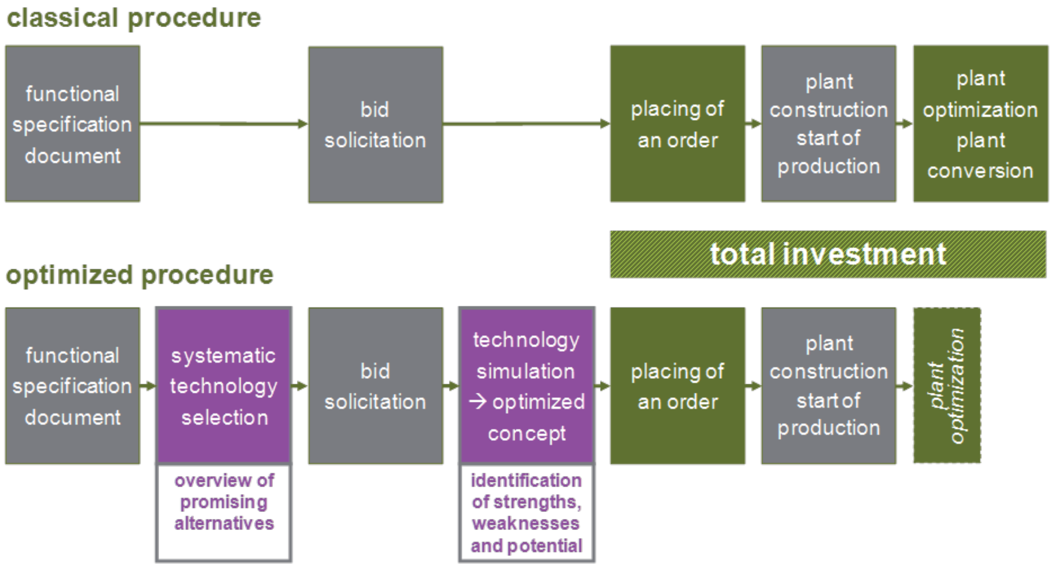

Figure 3. Procedure of investment decisions.

- a systematic market overview of promising technical alternatives
- holistic evaluation process by simulating the technical performances of the chosen alternatives to identify strengths, weakness and potentials.

Tools – LCA, LCC and life cycle models

EVALUATION OF ENVIRONMENTAL ASPECTS

The procedure of Life Cycle Assessment (LCA, see Figure 4) is established since 1996 and revised in 2006 with the ISO standards 14040 and 14044. It is common consensus to measure with this tool the ecological sustainability of products, technologies and services [3, 4]. LCA is a procedure in three steps: goal and scope definition, inventory analysis and impact assessment, combined with the interpretation of all results. A detailed description of the procedure and its application is available in the ILCD handbook [5].

EVALUATION OF ECONOMIC ASPECTS

Economic sustainability of complex systems can be measured by Life Cycle Costing. It is a best practise approach which amends and enhances the established cost calculation methods. The application is distinguished in two possibilities (Figure 5), i.e.:

- life cycle of a product such as an electric vehicle (static costs cover the current situation, dynamic costs include e.g. development of energy price
- life cycle of a capital good such as a coat shop for automobiles. (static costs cover the current situation, dynamic costs include e.g. development of all operational costs [material, energy, manpower, maintenance, recycling]).

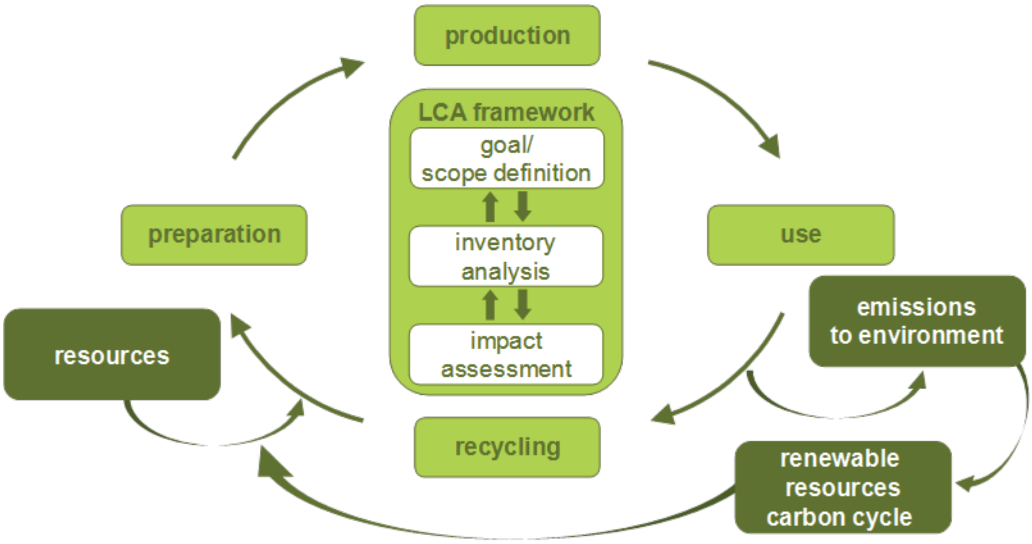

Figure 4. Life Cycle Assessment (LCA, ISO Standards 14040 & 14044).

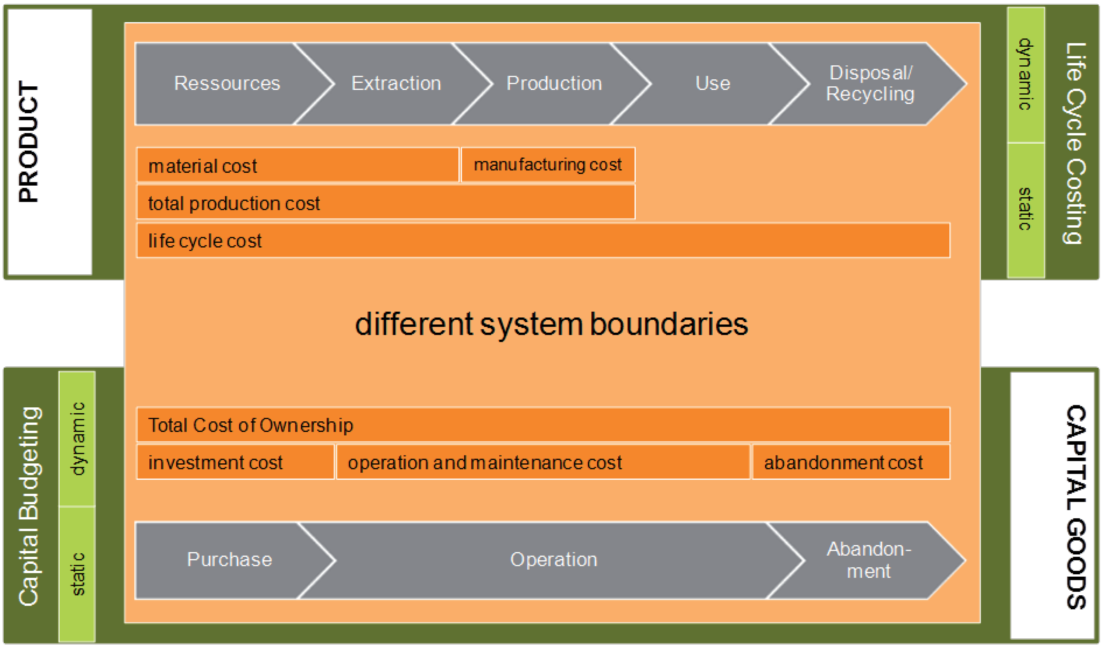

Figure 5. Life Cycle Costing (LCC).

LCS LIFE CYCLE SIMULATION MODELS

The structure of life cycle simulation models is kept simple and is strongly guided by the customers' needs. Depending on the scope, the system under study is categorized in subsections (such as spray booth, flash off, etc., compare Figure 7). For each of those there are reasonably parameterized process models created based on input-output analysis. This part of a life cycle model defines quantity and quality of involved materials, waste, emissions and kinds of energy. The information that feeds the quantitative life cycle inventory is primarily coming from bills of material, drawings, facility layouts, bills from the purchasing department and actual metering of energy and material consumption.

Then the resulting model is linked with the general setup and boundary conditions so that the use of the technology can be realistically simulated. This basic life cycle model can then be calibrated by adding available site specific consumption (material, energy) and cost information.

The resulting models are simple yet powerful and accurate tools that can be applied to almost any system (product, process, production site). They can be crucial parts of product comparisons, holistic technology benchmarks, scenario analysis, analysis of optimization potentials, etc. (Figure 6).

Application/Example

In the following LCA and LCC is applied to a plastic coating process. This choice was made because of the high economic (expensive process technology due to many process steps and high quality requirements for the final appearance of the surface) and environmental impacts (VOC and CO_2 emissions and high material and energy demand). In addition, many plastic products are coated due to quality requirements which are not obvious for many consumers. Examples are exterior (e.g. bumpers, outside mirrors) and interior parts (switches) for automobiles, cabinets for medical hardware, vacuum cleaner, etc.

First of all the goal and scope of the life cycle investigation have to be defined.

Goal:

- Ecological and economical modelling of coating process over life cycle, see Figure 7.
- Identification of important ecological and economical parameters.
- Demonstration of stepwise development potentials.

Scope:

- Functional unit: 1 m^2 coated plastic cabinet.
- One layer coating process for plastic cabinets (pretreatment not investigated for all development steps, assumed the same), end-of-life in this context is: recycling of used rinsing materials (used for cleaning of process equipment) and thermal incineration of coat solids overspray (i.e. coating process waste), see Figure 7.
- 2 shift production, 4.250 h/a, location Berlin (considering the climate data for energy demand of air conditioning).
- Solvent borne topcoat (50 % solids), layer thickness 40 µm, transfer efficiency 20 % (manual application process).
- Ecological parameters: PE = primary energy (total of heating values of all fossil resources, plus all renewable energies involved); ADP = abiotic resource depletion; GWP = green house warming potential (carbon footprint); POCP = photochemical oxidants creation potential; AP = acidification potential; EP = eutrophication potential.
- Economic parameters: material, energy, personnel, investment, maintenance and disposal costs of coating process.

The LCA is done as follows:

- Identification of all relevant process steps within the defined system boundaries of the investigation.
- Data collection for all energy and material flows, evaluation and verification for each process step, i.e. energy and material demand of coating process, calculation of material and energy ecoprofiles.
- Preparation of life cycle inventory (see Figure 8).
- Preparation of life cycle impact analysis and normalisation (see Figure 9 and Figure 10).
- Interpretation of results.

Figure 8 shows the primary energy demand for the material input (coat and rinse solvent) and for the process energy to coat one plastic cabinet. Additionally, the process energy is split in direct process energy and primary energy (which includes the complete supply chain, i.e. from cradle to the coating process). So the different efficiencies of energy supply become visible, i.e.

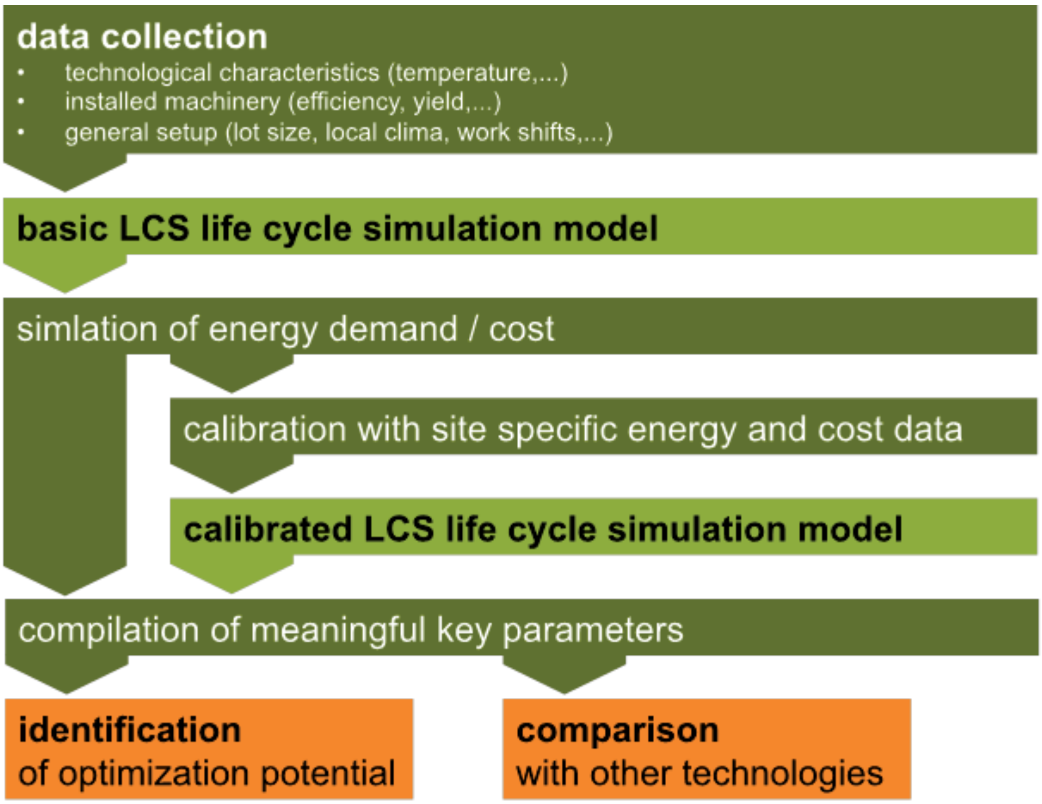

Figure 6. Evaluation process using LCS life cycle simulation models.

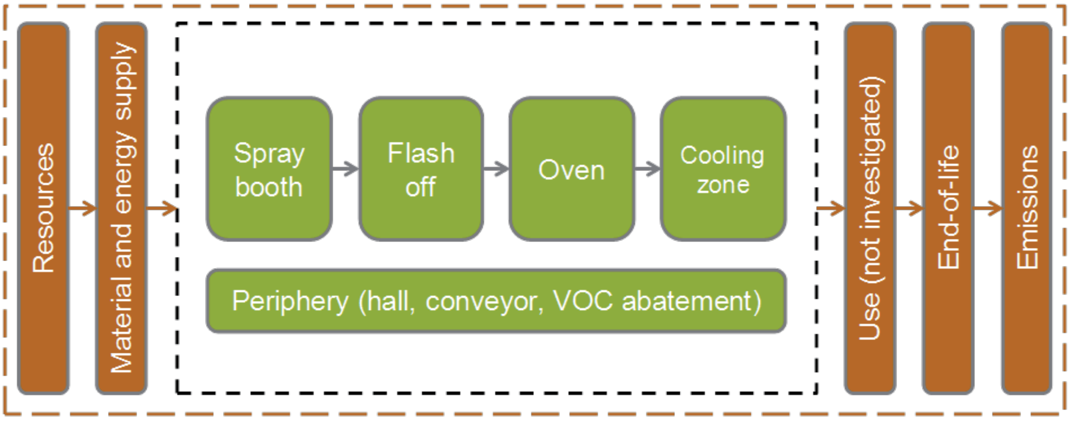

Figure 7. Definition of coating process (starting point).

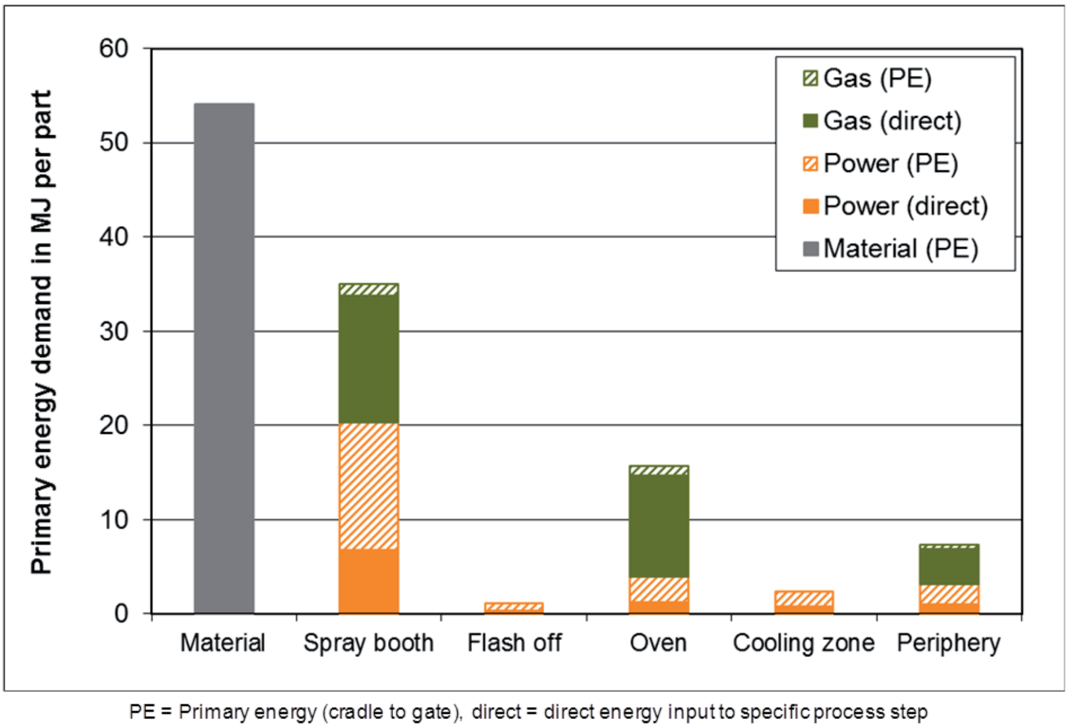

Figure 8. Coating process (starting point) – LCA coating process.

power generation (here: German power mix) and heat generation by gas.

Due to the low transfer efficiency (here: 20 %) the ecoprofile of the coat has a big influence to the ecological impact. Furthermore, the required air flow in the spray booth has a significant energy demand caused by air conditioning and ventilation (see Figure 8). The oven needs mainly heating energy. Periphery comprises the expenditure for the building.

Figure 9 exemplifies the procedure of normalization. Herewith, an identification of the most relevant impact category is best practice (compare Figure 10). In this case the yearly life cycle impacts of the coating process are set in relation to the yearly impacts of all EU 28 countries. The results are characteristics values without a specific unit which thus can be compared in their relative value.

Figure 10 shows the results of the normalization procedure with regard to the investigated coating process. Here the POCP value is dominating the evaluation due to the high VOC emissions of the applied solvent borne coat system. Such high VOC emissions are prohibited since the introduction of the VOC directive[3] in 2005 therefore technical (e.g. VOC abatement or new coat materials) developments are required which are investigated and evaluated with this business case. By the way this is a reasonable justification for the introduction of the VOC directive. If the VOC emissions are significantly reduced, e.g. by VOC incineration or by introducing water borne coat systems or by increasing the transfer efficiency of the application process, the environmental categories ADP (focus fossil energy consumption) and GWP (focus CO_2 emissions – so called carbon footprint) are getting in addition important.

3. VOC directive: Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds (VOC) due to the use of organic solvents in certain activities and installations.

The steps for LCC are:

- definition of economic boundary conditions of coating process (location, operation time, etc.)
- description of coating process and required equipment to obtain investment costs
- definition of demand and qualification of personnel to operate the coating process
- definition of energy and material demand and maintenance activities for coating process
- definition of recycling and disposal activities for coating process
- preparation of cost analysis
- interpretation of results.

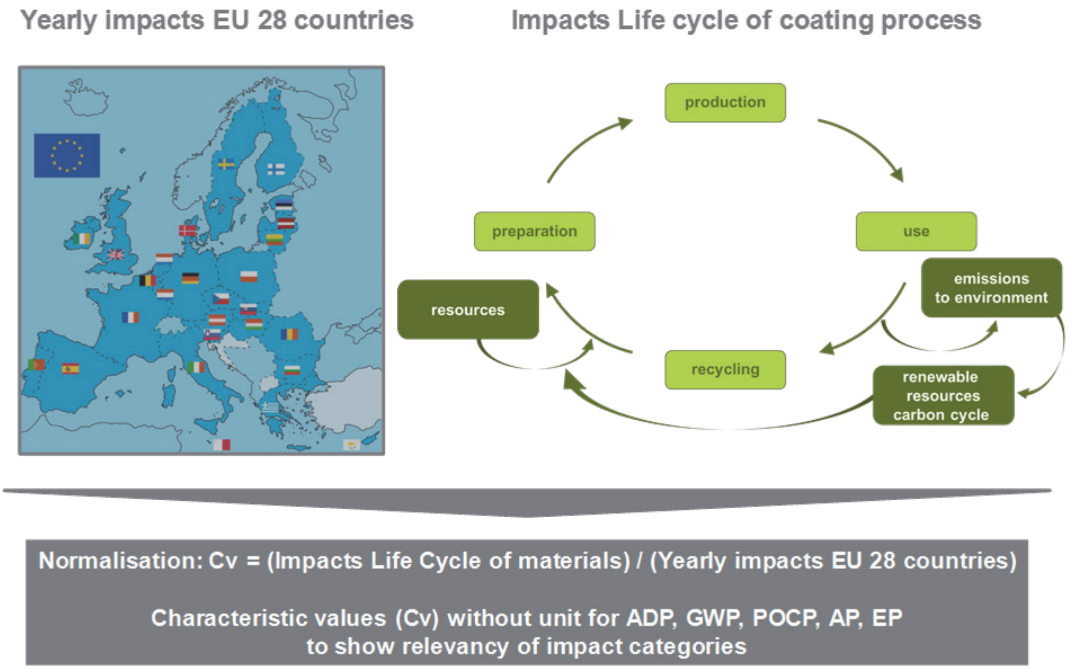

Figure 9. Normalization of resources and emissions.

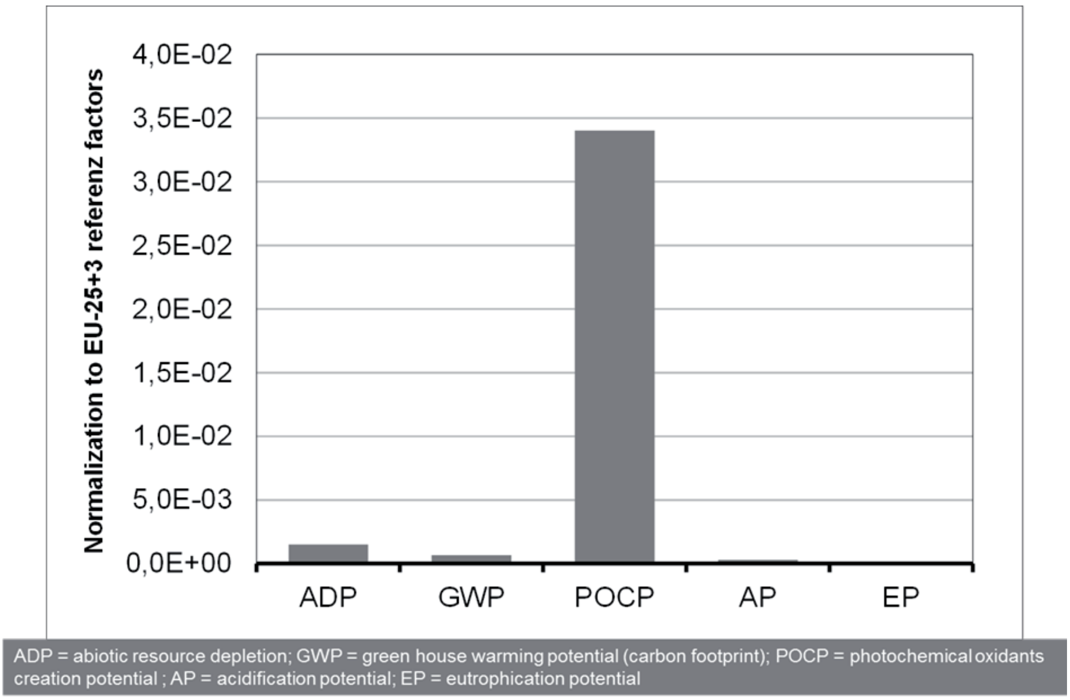

Figure 10. Coating process (starting point) – normalization of LCA results.

Figure 11 illustrates the distribution of costs of the investigated coating process. Due to the manual application process the personnel and material costs are dominating.

The detailed analysis of the coating process, including a life cycle model, can be ideally used as a starting point to investigate process and material optimization potentials or potentials of new technologies. This is carried out in a stepwise approach and demonstrated in Figure 12.

The investigated development steps are:

- step 1: implementation of VOC abatement (fulfilment of VOC directive)
- step 2: implementation of water borne coating (fulfilment of VOC directive)
- step 3: improvement of material and energy efficiency (water borne coat system)
- step 4: transfer of research results from BMBF-project ENSIKOM, high material efficiency by recycling of solids and solvents (solvent borne coat system), high energy efficiency (compact process + UV curing), no gas use [6].

Statements of Figure 12 are:

- Step 1: only implementation of VOC incineration (end-of-pipe technology) is not sustainable. VOC emissions are strongly decreased, but with the impact of higher primary energy demand and CO_2 emissions and higher costs.
- Step 2: only implementation of new coat system (here: water borne) is not sustainable. VOC emissions are strongly

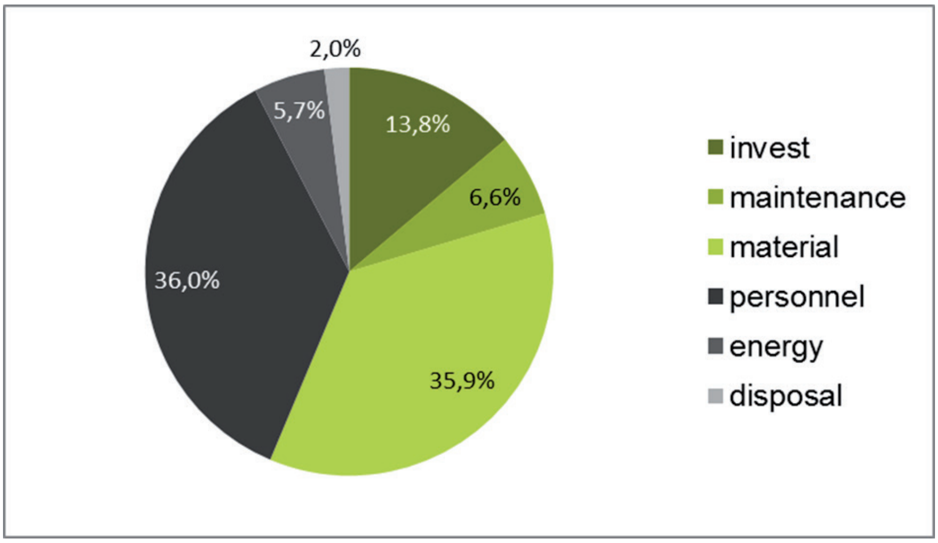

Figure 11. Coating Process (Starting Point) – LCC Coating Process.

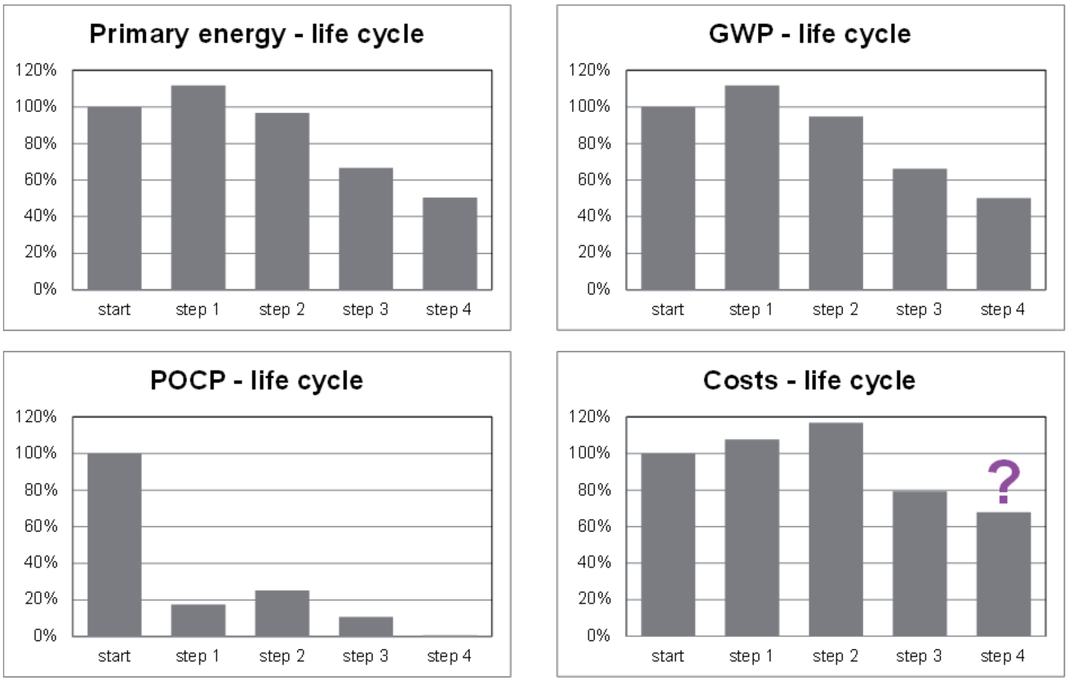

Figure 12. Development of coating process; from starting point to step 4.

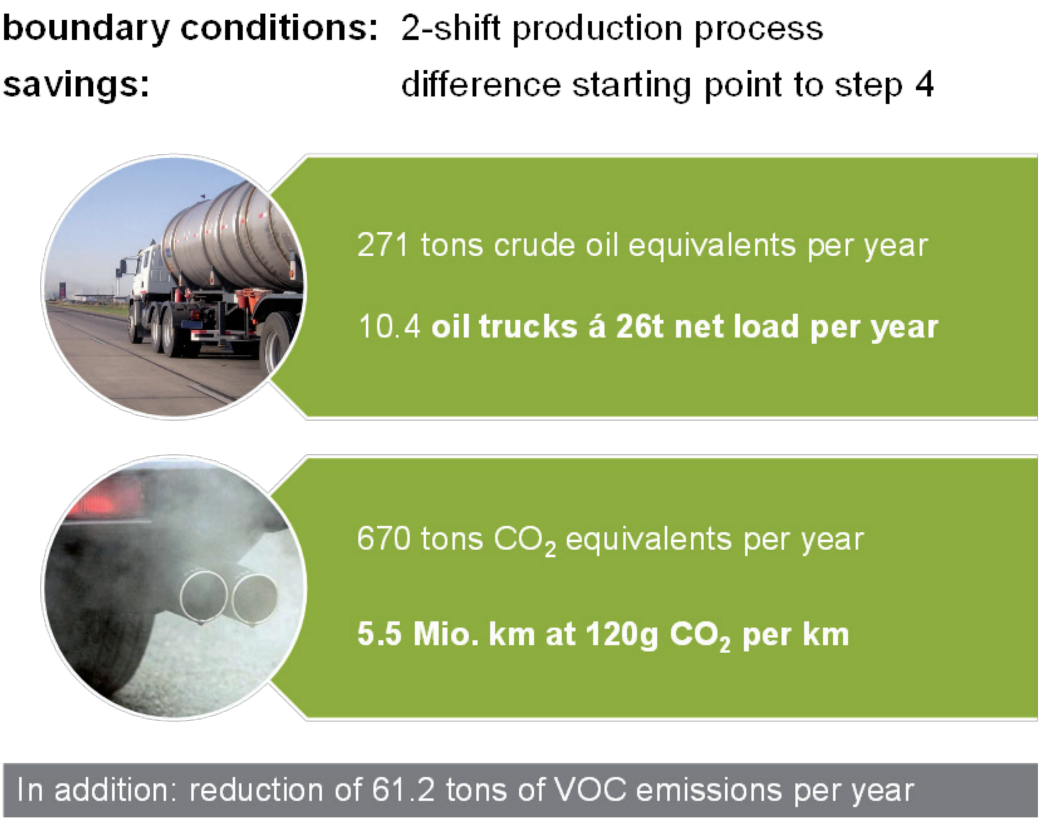

Figure 13. Life cycle optimization potential – estimation.

decreased, primary energy demand and CO_2 emissions are only slightly decreased, but with the impact of significant higher costs.

- Step 3: improvement of material and energy efficiency (e.g. introduction of robot application, energy efficiency in process technology [recirculating air flows, etc.]) has a significant positive impact to all investigated categories.
- Step 4: current research results show that improvements in ecological and in economic impacts are still significant and achievable without compromising the technical requirements. The question mark for the life cycle costs shall symbolize that this is an expert estimation depending strongly on the influence of the cost of the new high tech coat material under development.

Finally Figure 13 visualises the yearly ecological optimization potential introducing the new developed coating process (step 4) with regard to the starting point. Therefore, in a 2 shift coating process (4.250 h/a) energy and materials can be saved equivalent to 271 tons of crude oil equivalents (approx. 50 % reduction) and CO_2 emissions can be decreased by 670 tons (approx. 50 % reduction) and VOC emissions by 61 tons (approx. 99 % reduction).

Conclusion

This paper introduced the life cycle model approach for holistic investment decisions and demonstrated its application for a plastic coating process. Experiences from several business cases show that spread sheet based life cycle models:

- fairly characterize the status quo of an existing technology (economy, economy and long term impacts of both) and identify key technical parameters (yields or efficiencies of processes like transfer efficiency of coat application)
- can be used in the same way to analyse new investment options (i.e. new process equipment) and compare it to the status quo, i.e. strengths, weak points and potentials (and the knowledge which parameters or boundary conditions are responsible), compare Figure 3
- are an accepted communication platform to share on computers and execute user workshops (e.g. interactive scenario analysis of investment possibilities) in companies.

A specific conclusion of the shown business case (compare Figure 12) is that in terms of sustainability it is not decisive whether coat systems are solvent or water borne. For sustainability, the ecological and economic life cycle performance is essential.

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